REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 074-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE June 28, 2012	3. REPORT TYPE AND DATES COVERED Final; 10/15/2008 - 5/31/2012

4. TITLE AND SUBTITLE
Radar Imaging of Stationary and Moving Targets

5. FUNDING NUMBERS
FA9550-09-1-0013

6. AUTHOR(S)
Margaret Cheney

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Rensselaer Polytechnic
Institute
110 Eighth St.
Troy, NY 12180

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

AFOSR
ATTN: Dr. Arje Nachman
Program Manager,
Electromagnetics

875 North Randolph Road
Ste 325, Room 3112
Arlington, VA 22203

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

AFRL-OSR-VA-TR-2012-0506

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT
unlimited distribution -A

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 Words)***
This report summarizes work done on various radar imaging problems. Both stationary and moving targets are addressed, with single sensors and multiple sensors. Short summaries are included for the following dissertations:
Yi Fang ``Imaging with Sparse Measurements"
Hector Morales ``Synthetic-Aperture Radar Imaging through Dispersive Media"
Analee Miranda ``Imaging moving targets in a multipath environment with multiple sensors").
Kaitlyn Voccola ``Satistical and Analytical Techniques in Synthetic Aperture Radar"

14. SUBJECT TERMS
radar, SAR

15. NUMBER OF PAGES
24

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
unclassified	unclassified	unclassified	

Final Report
Radar Imaging of Stationary and Moving Targets
AFOSR Grant FA9550-09-1-0013

original dates: October 15, 2008 - September 30, 2011
no-cost extension until May 31, 2012

Principal Investigator: Margaret Cheney
Department of Mathematical Sciences
Rensselaer Polytechnic Institute
Troy, NY 12180
cheney@rpi.edu

June 28, 2012

Contents

Chapter 1

Project description

1.1 Objectives

Cheney's part of this project deals with radar remote sensing problems, including imaging and identification of stationary and moving targets.

Yazici's part of this project involves the development theoretical foundations for distributed radio-frequency imaging in complex environments

1.2 Personnel supported on this contract

1.2.1 Faculty

Margaret Cheney (Principal Investigator)
Birsen Yazici

Honors and Awards for Cheney

- Honorary Doctor of Science, Oberlin College, May 2012.
- Eisenbud Professor, Mathematical Sciences Research Institute, fall 2010.
- Fellow, Society for Industrial and Applied Mathematics (SIAM), 2009.

1.2.2 Cheney's graduate students supported on this contract

- Hector Morales , citizen of Mexico, Ph.D. December 2008. Thesis title: "Synthetic-Aperture Radar Imaging and Waveform Design for Dispersive Media". In 2008 only stipend and registration-in-absentia fees were charged.

- Yi Fang, citizen of China, Ph.D. December 2008. Thesis title: "Imaging from Sparse Measurements". In 2008 only stipend and registration-in-absentia fees were charged to this contract.

- Heather Palmeri's stipend and tuition for the spring of 2009 were charged to this contract. Heather (a U.S. citizen) is in our accelerated B.S./Ph.D. program. She has been working at Lincoln Lab during the summers, and her dissertation topic is related to Lincoln interests in ballistic missile defense.

- Scott Altrichter's stipend and tuition were charged to this contract for multiple years. Scott is a U.S. citizen.

1.2.3 Other students supervised by Cheney

The following students were not supported under this contract, but were supervised by Cheney.

- **Other Math graduate students (all U.S. citizens)**
  - Analee Miranda (Ph.D. Dec. 2010, "Imaging moving targets in a multipath environment with multiple sensors"). Her work was supported through a co-op at AFRL.
  - Kaitlyn Voccola (Ph.D. August 2011, "Satistical and Analytical Techniques in Synthetic Aperture Radar"). Her work was supported through the AFRL ATR Center.
  - Heather Palmeri (Ph.D. candidate, Math, 2008 - present). Her work is supported by an NSF Graduate Fellowship.
  - Tegan Wegster (Ph.D. candidate, Math, 2009 - present). Her work is supported by an NDSEG Fellowship.

  - Tom Zugibe (Ph.D. candidate, Math, 2009 - 2010, now working at Lincoln Laboratory)
  - Scott Altrichter (Ph.D. candidate, Math, 2009 - present)
  - Jerry Kim (Ph.D. candidate, Math, 2010 - present). His work is supported by the GI Bill.
  - Michael Levy (Ph.D. candidate, Math, 2010 - present). His work will be supported by the SMART program.
  - Chad Waddington (Ph.D. candidate, Math, 2011 - present)
  - Nick Lorenzo (Ph.D. candidate, Math, 2011 - present)
  - Sarah Farrell (Ph.D. candidate, Math, 2011 - 2012)

- **Supervision of undergraduate senior theses**
  - Tegan Webster, 2009
  - Daniel Baldewicz, 2012

1.2.4 Yazici's graduate student supported on this contract

Steven Wacks

Part I

Cheney's Work

Chapter 2

Transitions

2.1 Placements of Cheney's students

2009

- Kaitlyn Voccola and Analee Miranda spent the summer at AFRL.
- Analee Miranda began a co-op at AFRL.

2010

- Heather Palmeri spent the summer at Lincoln lab.
- Kaitlyn Voccola spent the summer at AFRL.
- Analee Miranda continued her co-op at AFRL; she finished her Ph.D. and took a government position at AFRL.
- Tom Zugibe received a Masters degree and took a position at Lincoln Laboratory in 2010.

2011

- Kaitlyn Voccola and Chad Waddington spent the summer at AFRL.
- Tegan Webster and Jerry Kim spent the summer at NRL.
- Michael Levy, Scott Altrichter, Nick Lorenzo, and Sarah Farrell did summer projects with me at RPI.

- Heather Palmeri spent the summer at Lincoln Lab.
- Kaitlyn Voccola finished her Ph.D. and accepted a National Research Council postdoc at AFRL.

2012

- Chad Waddington, Michael Levy, Nick Lorenzo, and Scott Altrichter are at AFRL for the summer.
- Chad Waddington will also spend the 2012-13 academic year at ARFL.
- Michael Levy has accepted a SMART Fellowship to work with RYAP.
- Tegan Webster and Jerry Kim are working on dissertations at NRL.
- RPI math & physics major Daniel Baldewicz has been accepted into the ECE department at Northeastern, to work with Prof. Edwin Marengo.

2.2 Efforts to bring the math community together with the radar signal-processing community

2.2.1 Visits to Laboratories

- summer 2012: American Society for Engineering Education Summer Faculty Fellow, Naval Research Laboratory, Washington DC
- multiple visits each year to AFRL (Dayton, Rome, San Antonio, once to Albuquerque) and the Naval Postgraduate School, and visits to the Naval Research Laboratory

2.2.2 Lecture Series and Conference Organization

- 2012: Co-organized 4 minisymposia on radar at the SIAM Conference on Imaging Science, May 20-22, 2012, Philadelphia.
- 2012: Organizer, IPAM workshop "Problems in Synthetic-Aperture Radar", Feb. 6-10, 2012.

- Dec. 12, 2011, “Introduction to Radar Imaging”, one of 3 hour-long lectures at the workshop on Inverse Problems in Science and Engineering, Isaac Newton Institute, Cambridge, England.

- July 4-9, 2011, Lecturer at “Waves and Imaging”, Gene Golub SIAM Summer School, Vancouver, CA. 10 hours of lectures plus 5 hours of computer lab sessions.

- August 16 - Dec. 15, 2010, Long-term visitor, program on Inverse Problems and Applications, Mathematical Sciences Research Institute. Member of Organizing Committee for introductory workshop at MSRI

- June 14-18, 2010, arranged for AFRL (Matt Ferrara) to present a problem at the Mathematical Problems in Industry Workshop, RPI

- 2009 - 2010: Member of Organizing Committee, SIAM Conference on Imaging Science, April 12-14, 2010 in Chicago, Illinois.

- 2006-2008: Program Director, SIAM Activity Group on Imaging Science (elected), Organizer of SIAM Imaging Science Conference, July 7-9, 2008.

2.2.3 Monograph

Fundamentals of Radar Imaging, M. Cheney and B. Borden, SIAM, Philadelphia, 2009. Has sold more than 500 copies in the first 18 months.

This book explains the fundamentals of radar imaging to a mathematical audience. We hope that this book will enable mathematicians to begin work in radar imaging.

2.2.4 Lectures

- May 1, 2011, “Introduction to Synthetic-Aperture Radar Imaging”, plenary talk, Union College Mathematics Conference, Schenectady, NY.

- January 4, 2011, “Waveform-diverse, moving-target spotlight SAR”, AFOSR Electromagnetics Workshop, San Antonio, TX.

- Dec. 14, 2010, “Imaging from limited data”, Workshop on Materials Tomography, Dayton, OH.

- Nov. 11, 2010, "Waveform-diverse, moving-target spotlight SAR", MSRI Workshop on Inverse Problems: Theory & Applications.
- Oct. 11, 2010, "Introduction to Radar Imaging", MSRI/Evans lecture, Berkeley, CA.
- August 23-25, 2010, "Introduction to Radar Imaging", series of 3 lectures at MSRI Introductory Workshop on Inverse Problems.
- August 10, 2010, "Waveform-diverse, moving-target spotlight SAR", Waveform Diversity & Design conference, Niagara Falls.
- June 10, 2010, "Multistatic Radar Imaging of Moving Targets", Sensing, Surveillance, and Navigation AFOSR Program Review, Boston, MA.
- May 21, 2010, Plenary lecture: "Radar Imaging", Frontiers of Applied and Computational Mathematics, New Jersey Institute of Technology.
- May 12, 2010, "Multistatic Radar Imaging of Moving Targets", IEEE Radar Conference, Washington, D.C.
- April 13, 2010, "Microlocal Analysis in Radar Imaging", SIAM Conference on Imaging Science, April 12-14, 2010 in Chicago, Illinois.
- January 12, 2010, "Radar Imaging", Purdue University Mathematics Colloquium.
- January 5, 2010, "Radar Imaging", AFOSR Electromagnetics Workshop, San Antonio, TX.
- January 7, 2009, "Radar Imaging", AFOSR Electromagnetics Workshop, San Antonio, TX.
- May 7, 2009, "Spatial, Temporal, and spectral aspects of radar data", IEEE Radar Conference, Pasadena, CA
- October 28, 2008, "Radar Imaging with Temporal, Spectral, and Spatial Diversity", Forty-Second Asilomar Conference on Signals, Systems, and Computers, Asilomar, CA.

2.2.5 Editorial work

- 1998 - present: Member of editorial board for Inverse Problems
- 2006 - present: Member of editorial board for AIMS journal Inverse Problems and Imaging
- 2007 - 2009: Member of editorial board for new SIAM Journal on Imaging Science
- 2008 - 2011: Member of editorial board for IEEE Transactions on Image Processing

Chapter 3

Technical Results (Cheney)

3.1 Publications

In addition to the book mentioned above, the following have been published.

3.1.1 Journal Papers

1. "Imaging Moving Targets from Scattered Waves", M. Cheney and B. Borden, Inverse Problems 24 (2008) 035005.

   This paper was posted in early April 2008. In late April this paper was selected for inclusion in IoP Select; this selection is based on the criteria

   - Substantial advances or significant breakthroughs
   - A high degree of novelty
   - Significant impact on future research

   By the end of May, this article had been downloaded 250 times. (Across all IoP journals, only 10% of articles were downloaded over 250 times during the first quarter of 2008.) As of Dec. 1, it had been downloaded 500 times. (Across all IOP journals, only 3% of articles were accessed over 500 times in 2008.) This was also the article chosen from 2008 for the special 25th anniversary collection posted at http://iopscience.iop.org/0266-5611/page/25th%20Year%20Anniversary%20Collection .

2. “Problems in synthetic-aperture radar imaging”, M. Cheney and B. Borden, Inverse Problems, Vol 25, pp. 123005 (2009).

   This paper was downloaded 250 times in 22 days from the date of publication. To put this into context, across all IOP journals 10% of articles were accessed over 250 times this quarter.

3. “Synthetic-aperture imaging through a dispersive medium”, T. Varslot, H. Morales, M. Cheney, Inverse Problems 26 (2010) 025008.

4. “Imaging from sparse measurements”, Y. Fang, M. Cheney, S. Roecker, Geophysical Journal International, Volume 180 Issue 3, Pages 1289 - 1302, Published Online: 22 Jan 2010.

5. “Multistatic Radar Imaging of Moving Targets”, L. Wang, M. Cheney, B. Borden, IEEE Trans. Aerospace & Electronic Systems,

   This paper shows simulations corresponding to the theory developed in item 1 above. Surprisingly, it shows that for certain geometries, it may be possible to simultaneously determine location and velocity of a distribution of moving targets.

6. “Waveform Design for Synthetic-Aperture Radar Imaging through Dispersive Media”, T. Varslot, J. H. Morales, and M. Cheney, SIAM J. Appl. Math., Vol.71, No.5, DOI 10.1137/100802438, published online 5 Oct 2011.

   This paper addresses the question of what waveforms are best for imaging through dispersive media. The answer depends on the noise level; for high noise levels, precursor-like waveforms are best.

7. “Waveform-Diverse Moving-Target Spotlight Synthetic-Aperture Radar”, M. Cheney and B. Borden, SIAM J. Imaging Science 4, pp. 1180-1199, published online 13 December 2011; DOI: 10.1137/100808320 ; posted on arXiv May 16, 2011.

   This paper develops theory for Synthetic-Aperture Radarin which different waveforms can be transmitted at every pulse, including cases when the start-stop approximation does not necessarily hold.

3.1.2 Conference Proceedings and Book Chapters

1. T. Varslot, B. Yazici, E. Yarman, M. Cheney, L. Scharf, "Time-reversal Waveform Preconditioning for Clutter Rejection" Principles of Waveform Diversity and Design, ed. Michael Wicks, Eric Mokole, Shannon Blunt, Richard Schneible, Vincent Amuso, SciTech Publishing, Inc., 2010.

2. K. Voccola, B. Yazici, M. Ferrara, and M. Cheney, "On the relationship between the generalized likelihood ratio test and backprojection for synthetic aperture radar imaging", in Automatic Target Recognition XIX, ed. Firooz A. Sadjadi, Abhijit Mahalanobis, Proc. SPIE 7335, 73350I (2009); doi:10.1117/12.818554

3. M. Cheney, L. Wang, and B. Borden, "Spatial, Temporal, and Spectral Aspects of Radar Data", Proceedings of IEEE Radar Conference, May 2009, Pasadena, CA.

4. Yi Fang, M. Cheney,S. Roecker, "Multistatic radar imaging from sparse measurements", Proceedings of IEEE Radar Conference, May 2010, Arlington, VA.

5. L. Wang, M. Cheney, and B. Borden, "Multistatic radar imaging of moving targets", Proceedings of IEEE Radar Conference, May 2010, Arlington, VA.

6. M. Cheney and B. Borden, "Waveform-diverse moving-target spotlight SAR", in proceedings of International Waveform Diversity and Design Conference (WDD), 8-13 Aug. 2010, doi: 10.1109/WDD.2010.5592340

7. "Synthetic-aperture radar imaging", M. Cheney and B. Borden, ch. 15 in Handbook of Mathematical Methods in Imaging, Springer 2011, Pages 655-690.

8. M. Cheney and B. Borden, "Waveform-diverse moving-target spotlight SAR", in Algorithms for Synthetic Aperture Radar Imagery XV, ed. E.G. Zelnio and F.D. Garber, Proceedings of SPIE Defense, Security, and Sensing Conference, vol. 8051, 80510T (2011); doi:10.1117/12.883310

9. T. Varslot, B. Yazici, M. Cheney, "Wideband pulse-echo imaging using distributed apertures in multi-path," IEEE Radar Conference, May, 2008, Rome, Italy.

10. "Wideband pulse-echo imaging using distributed apertures in multipath," T. Vaslot, B. Yazici, M. Cheney, SPIE Defense and Security Conference, April, 2008, Orlando, FL.

11. A. Miranda and M. Cheney, "Imaging moving targets in a multipath environment with multiple sensors", International Conference on Electromagnetics for Advanced Applications, Torino, Italy, 2011. Proceeding of the IEEE.

12. T. Webster, J. Kim, I. Bradaric, and M. Cheney, "Deterministic and Statistical Models for Multistatic Ambiguity Functions", IEEE Radar Conference, May 2012, Atlanta, GA.

13. K. Voccola, M. Cheney, and B. Yazici, "Polarimetric Synthetic-Aperture Inversion for Extended Tagets in Clutter", IEEE Radar Conference, May 2012, Atlanta, GA.

14. A. Miranda and M. Cheney, "Imaging with waves bounced from a dispersive reflector", IEEE Radar Conference, May 2012, Atlanta, GA.

15. "Imaging that exploits spatial, temporal, and spectral aspects of far-field radar data", M. Cheney and B. Borden, Algorithms for Synthetic Aperture Radar Imagery XV, ed. E.G. Zelnio and F.D. Garber, Proceedings of SPIE Defense & Security Conference, vol. 6970 (2008) 6970 0I doi: 10.1117/12.777416.

16. "Waveform Preconditioning for Clutter Rejection in Multipath for Sparse Distributed Apertures," T. Varslot, B. Yazici, C.E. Yarman, M. Cheney, L. Sharf, Proceedings of The Second International Workshop on Computational Advances in Multi-Sensor Adaptive Processing (CAMSAP), pp. 181-184, December 2007.

3.1.3 Papers in review or in press

- "Polarimetric Synthetic-Aperture Inversion for Extended Targets in Clutter", K. Voccola, M. Cheney, and B. Yazici, submitted to Inverse Problems, Dec. 2011.

- "Imaging Frequency-Dependent Reflectivity from Synthetic-Aperture Radar", submitted to Inverse Problems, Jan. 9, 2012.

- "Radar imaging", M. Cheney and B. Borden, submitted to Springer Encyclopedia of Applied and Computational Mathematics, 2011.
- "Multistatic Radar Waveforms for Imaging of Moving Targets", M. Cheney, B. Borden, and L. Wang, submitted to Proceedings of the February Fourier Talks (2006-2010), part of Springer-Birkhauser Applied and Numerical Harmonic Analysis (ANHA) book series

3.2 Dissertations supervised by Cheney

3.2.1 Yi Fang's Dissertation

Ph.D. dissertation"Imaging from Sparse Measurements", Yi Fang, December 2008. It is available at
`http://eaton.math.rpi.edu/faculty/Cheney/theses/YiFangThesis.pdf`

This dissertation considers the inverse problem for the scalar wave equation with sparse and non-equally spaced sources and receivers. The key problem is to develop a method to weight different parts of the data differently to compensate for nonuniform sampling.

The theory uses the single-scattering (Born) approximation and an inversion formula based on a filtered version of the adjoint operator of the forward model. The resolution of the reconstruction is studied by means of the point-spread function. For sparsely positioned sources and receivers, the point-spread function can be approximated by a weighted sum of oscillatory functions. A regularized least-squares method can be formulated to determine weights that make the point-spread function as close as possible to the Dirac delta function. Once the weights are determined, the same set of weights can be applied to form an image from measured data.

The minimization scheme is tested with different regularization parameters. The sensitivity of the reconstruction with respect to noise and positioning error is tested. The regularization parameters can be chosen to improve resolution and gain stability at the same time.

The dissertation includes examples of point-spread functions constructed with weights corresponding to three different types of source-receiver geometry with different frequency bands. These results not only show that using the right weights improves the resolution relative to reconstructions with constant weights, but also illustrate the relation between resolution and the source-receiver geometry and bandwidth.

3.2.2 Hector Morales' Dissertation

Ph.D. dissertation "Synthetic-Aperture Radar Imaging and Waveform Design for Dispersive Media", José Héctor Morales Bárcenas, December 2008. It is available at
`http://eaton.math.rpi.edu/faculty/Cheney/theses/HectorMoralesThesis.pdf`

This dissertation develops a method for synthetic-aperture radar (SAR) imaging through a dispersive medium and we provide a method to obtain the optimal waveform design for imaging.

The dissertation considers the case when the sensor and scatterers are embedded in a homogeneous dispersive material, and the scene to be imaged lies on a known surface. The development uses a linearized (Born) scalar scattering model, and allows the flight path of the radar antenna to be an arbitrary smooth curve.

A filtered back-projection imaging algorithm is developed in a statistical framework where the measurements are polluted with thermal noise. The theory assumes that prior knowledge about the power-spectral densities of the scene and the noise are available.

The algorithms are tested for the case when the scene consists of point-like scatterers located on the ground. The position of the targets is well resolved when the target-to-noise ratio is relatively small. For relatively large noise levels, the position of the targets are still well resolved employing the optimal waveform as an input signal in the reconstruction algorithm.

The dissertation includes the results of simulations in which the dispersive material is modeled with the Fung-Ulaby equations for leafy vegetation. However, the method is also applicable to other dielectric materials where the dispersion is considered relevant in a frequency range of the transmitted signals.

3.2.3 Analee Miranda's Dissertation

Ph.D. dissertation "Imaging Moving Targets in a Multipath Environment with Multiple Sensors" Analee Miranda, December 2010. It is available at
`http://gradworks.umi.com/34/48/3448428.html`

This dissertation develops a method for designing a wave-based imaging system that utilizes multiple sensors effectively in the presence of multipath wave propagation. The dissertation addresses the cases where the individual transmit/receive sensors are separated by large distances. The scene to be imaged has been illuminated by direct path and multipath wave propagation. The scattering objects of interest are moving. The dissertation develops a model for the received data that is based upon the distorted wave Born approximation. The multipath wave propagation is modelled by a reflecting surface.

Data models are developed for two cases: one where the reflecting surface is perfectly reflecting and one where the reflection medium depends on frequency and take-off angle. Then a number of inversion formulas are developed, based on various versions of a filtered adjoint operator of the forward model. The varying inversion formulas account for the waves that have arrived via different paths. Finally, the appropriate point-spread function is derived for each case. Numerical experiments are reported in which the forward data is numerically simulated, and then used to reconstruct an image. Several sensor configurations of the imaging system are tested.

3.2.4 Kaitlyn Voccola's Dissertation

Ph.D. dissertataion "Statistical and Analytical Techniques in Synthetic Aperture Radar Imaging", Kaitlyn Voccola, August 2011. It is available at
`http://eaton.math.rpi.edu/faculty/Cheney/theses/VoccolaThesisfinal.pdf`.

In synthetic-aperture radar (SAR) imaging, a scene of interest is illuminated by electromagnetic waves. The goal is to reconstruct an image of the scene from the measurement of the scattered waves using airborne antenna(s). This thesis is focused on incorporating statistical modeling into imaging techniques.

The thesis first considers the relationship between backprojection in SAR imaging and the generalized likelihood ratio test (GLRT), a detection and estimation technique from statistics. Backprojection is an analytic image reconstruction algorithm. The generalized likelihood ratio test is used when one wants to determine if a target of interest is present in a scene. In particular it considers the case when the target depends on a parameter which is unknown prior to processing the data. Under certain assumptions, namely that the noise present in the scene can be described by a Gaussian distribution, we show that the test statistic calculated in the GLRT is equivalent to the value of a backprojected image for a given location in the scene.

Next the task of developing an imaging algorithm for extended targets embedded in clutter and thermal noise is addressed. Theory for the case of a fully polarimetric radar system is developed. Scatterers in the scene are assumed to be made up of dipole scattering elements in order to model the directional scattering behavior of extended targets. The imaging approach developed is a statistical filtered-backprojection scheme in which the clutter, noise, and the target are all represented by stochastic processes. A bakcprojection filter is derived that minimizes the mean-square error between the reconstructed image and the actual target. This work differs from standard polarimetric SAR imaging in that we do not perform channel-by-channel processing. The conclusion is that it is preferable to use a coupled processing scheme in which all sets of collected data are used to form all elements of the scattering matrix. The numerical experiments show that not only is mean-square error minimized but also the final signal-to-clutter ratio is reduced when utilizing the new coupled processing scheme.

Chapter 4

Current Status of Effort

- Effort is ongoing to supervise Heather Palmeri as she finishes her dissertation. Her work extends some of the work of Mark Stuff and Matt Ferrara.
- A journal paper from Analee Miranda's dissertation is in preparation.
- Dissertation topics have been chosen for Tegan Webster and Jerry Kim.
- A journal paper on Michael Levy's work is in preparation.
- Supervision of Jerry Kim, Tegan Webster, Scott Altrichter, and Michael Levy is ongoing. All these students are doing dissertation work.
- Advising of Nick Lorenzo and Chad Waddington is ongoing.
- Work on frequency-dependent imaging in ongoing to incorporate characteristics of typical systems.
- Joint work is continuing with Matt Ferrara and Jason Parker to finish a paper following from our discussions at the Mathematical Problems in Industry Workshop.

Part II

Yazici's work

4.1 Summary

In the last several years Dr. Yazici has been involved in research to develop theoretical foundations for distributed RF imaging in complex environments and to provide corresponding constructive algorithms towards the realization of such systems. Her research uses ideas in estimation-detection theory, microlocal analysis, non-commutative harmonic analysis and inverse scattering theory. During the period 11/09 – 4/12, the main themes of her research have been multi-static imaging, exploiting multiple-scattering, passive imaging, moving target imaging and ultra-narrowband waveforms. Specifically, Dr. Yazici's research in the last two years related to distributed RF sensing in complex environments can be found in the following references: For multistatic synthetic aperture imaging, see [12]. For multi-static synthetic aperture imaging exploiting multiple-scattering, see [9]. For a novel passive synthetic aperture imaging modality using ultra-narrowband waveforms, see [10,6,7]. For passive imaging of stationary targets using sparse distributed apertures in multiple-scattering environments, see [11]. For passive imaging of moving targets using sparse distributed apertures in free-space and multiple-scattering environments, see [3], [5]. For bi-static synthetic aperture imaging using ultra-narrowband waveforms, see [4]. For synthetic aperture imaging of moving targets using ultra-narrowband continuous waveforms, see [1],[2]. For a novel inversion of circular averages transform (the transform involved in mono-static SAR) using the harmonic analysis over the sphere, see [8].

4.2 List of Journal Publications acknowledging FA9550-09-1-0013.

1. L. Wang, B. Yazici, "Bistatic Synthetic Aperture Imaging of Moving Targets using Ultra-narrowband Continuous Waveforms," submitted to Inverse Problems, 2012.

2. L. Wang, B. Yazici, "Ground Moving Targets Imaging using Ultra-narrowband Continuous Waveform Synthetic Aperture Radar," [invited] submitted to IEEE Transactions on Geosciences and Remote Sensing, Special issue on Synthetic Aperture Radar, 2012.

3. L. Wang, B. Yazici, “Passive Moving Target Imaging Exploiting Multiple Scattering using Sparse Distributed Apertures,” in review. Inverse Problems.

4. L. Wang, B. Yazici, “Bi-static Synthetic Aperture Imaging using Ultranarrowband Continuous Waveforms,” to appear in IEEE Transactions on Image Processing.

5. L. Wang, B. Yazici, “Passive Moving Target Imaging using Sparse Distributed Apertures,” to appear in SIAM Journal on Imaging Science.

6. L. Wang, C. E. Yarman, B. Yazici, ”Theory of Passive Synthetic Aperture Imaging,” to appear in the Proceedings of the FFTs, Springer-Birkhauser Applied and Numerical Harmonic Analysis (ANHA) book series, Editors: R. Balan, J. Benedetto, W. Czaja, and K. Okoudjou.

7. L. Wang, C. E. Yarman, B. Yazici, “Doppler-Hitchhiker: A Novel Passive Synthetic Aperture Radar using Ultra-Narrowband Sources of Opportunity,” IEEE Trans. on Geosciences and Remote Sensing, Vol. 49, No. 12, pp: 3521-3537, October 2011.

8. C.E. Yarman, B. Yazici, “Inversion of circular averages transform using the Funk transform,” Inverse Problems 27 (2011) 065001 (16 pages), June 2011. [Highlight article of 2011 in Inverse Problems Journal.]

9. V. Krishnan and B. Yazici, “Synthetic Aperture Imaging Exploiting Multiple-Scattering,” Inverse Problems, 055004 (25 pages), May 2011.

10. C.E. Yarman, L. Wang, B. Yazici, ”Doppler Synthetic Aperture Hitchhiker Imaging,” Inverse Problems, Vol. 26, pp: 065006(26 pages), May 2010.

11. L. Wang, I.Y Son, B. Yazici, ”Passive Imaging using Distributed Apertures in Multiple Scattering Environments,” Inverse Problems, Vol. 26, pp: 065002(37 pages), May 2010.

12. V. Krishnan, J. Swoboda, C.E. Yarman, B. Yazici, ”Multi-static Synthetic Aperture Radar Image Formation,” IEEE Transactions on Image Processing, Vol. 19, No. 5, pp: 1290-1306, 2010.